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SOUND VELOCITY AND ELASTIC MODULI MEASUREMENTS ON SEVERAL TNT-BASE EXPLOSIVE COMPOSITIONS (U)

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U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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SOUND VELOCITY AND ELASTIC MODULI MEASUREMENTS ON SEVERAL TNT-BASE EXPLOSIVE COMPOSITIONS

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ABSTRACT: The velocity of longitudinal and transverse acoustical disturbances were measured for a number of cast explosive compositions in bar form by the disturbance resonance technique. Young's modulus, E, and the shear modulus, G, for the explosives have been derived from these measurements. At loading densities $\sim$98% of theoretical maximum and temperatures of 22 to 25°C the following values were obtained:

Explosive	Sound Velocities (m/sec) Long.	Trans.	Elastic Moduli (dynes/cm^2) x 10^{10} E	G
TNT	1980	1230	6.42	2.48
Comp B	2420	1520	9.93	3.92
Comp B +1% wax	2290	1570	9.05	4.16
Comp B +2% wax	2430	1540	9.97	3.96
Comp B +3% wax	2410	1520	9.68	3.86
75/25 cyclotol	2510	1560	10.8	4.17
50/50 pentolite	2240	1410	8.66	3.34
H-6	2490	1570	11.1	4.25
HBX-1	2450	1520	10.5	3.97
67/33 baratol	2280	1440	13.0	5.17

The range in observations for these sound velocity measurements was on the order of 2 to 3%. The sound velocities are estimated reproducible to 1 to 2%; the computed moduli are therefore reproducible to 2 to 4%. It is observed, however, that results of this type are highly dependent upon the state and conditions of preparation of the particular charges used in the measurements. Corrections to apply to the results are discussed. The results for TNT are compared to those of other investigators.

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This report presents the results of an investigation of the physical properties of explosives undertaken by a summer employee of the Laboratory. The work was started in the summer of 1956 and completed in the summer of 1957. Publication has been delayed because of transfer of the author from the Laboratory and the press of urgent tasks.

The work was undertaken as part of the Laboratory's overall work in chemistry and explosives research. This particular phase of these efforts are intended to fill, in part, a gap in knowledge on the physical behavior and characteristics of explosives. The results should be of interest both to scientists concerned with a better understanding of explosives and the response of explosives to external stimuli and to engineers concerned with the use of explosives.

This work was carried out with the support of the Bureau of Naval Weapons (formerly Bureau of Ordnance) under Wep Task RUME 3E012/212 1/F008 10 004, Properties of Explosives (formerly BuOrd Task 301-664/43006/08040, Explosives Applied Research).

A number of people in addition to the author contributed to this work. These include, among others, R. H. F. Stresau, J. N. Ayres, I. Kabik, and the explosives charge preparation group of the Chemical Engineering Division.

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INTRODUCTION

This report presents the results of a series of experiments undertaken to determine the velocities of sound of various explosives in cylindrical bar form and the computation of Young's modulus, E, and the torsional or rigidity modulus, G, for the explosives, based on the sound velocity measurements.

Young's modulus for a material in the form of a long cylindrical bar could be found in a straightforward manner by application of its definition

$$E = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{d/L},$$

where F is the force applied to the end of the long bar, A is the bar's cross-sectional area, L is its length, and d is the corresponding change in length that is produced by the force measured with respect to the other end of the bar held fixed. The torsional modulus of the bar could be found by use of the equation[1]

$$G = \frac{2TL}{\pi \phi R^4},$$

where T is the torque applied to one end of the bar, R is the bar's radius, L is its length, and ϕ is the angular deformation of the bar measured with respect to the other end of the bar held fixed.

These elastic constants could also be found from the relationships between these constants and the velocities of acoustic wave propagation in a sample of the material.[1] Thus:

$$v = (E/\rho)^{1/2} \; ; \; E = \rho v^2$$

and

$$V = (G/\rho)^{1/2} \; ; \; G = \rho V^2$$

where v is the longitudinal elastic wave velocity, V is the transverse (torsional) elastic wave velocity, and ρ is the material density. The elastic moduli given here will be computed from these equations.

THE EXPERIMENTAL ARRANGEMENT

The velocities of the acoustic elastic waves in the test specimens were measured by a disturbance resonance technique (see, for instance, W. S. Cramer[2]). The experimental arrangement used for these measurements is shown in Figure 1. The samples were taken in rod-like form with length about 15 inches and diameter 1 inch. Coils similar to loud-speaker voice coils were mounted firmly on each end of the sample and the assembly was then arranged so that it hung freely with the coils in the fields of permanent magnets set near the ends of the sample. An oscillator energized the coil on the driver end of the sample in the field of magnet M1 to excite the waves in the sample. Arrival of these waves at the opposite end of the sample vibrated the coil attached there in the field of magnet M2 thereby generating a voltage that signaled the passage of the wave through the sample.

The arrangements of the coils on the driver end of the samples needed to produce the desired forces and the mounting of the coils on the sample are shown in Figure 2:

> <u>Longitudinal Forces</u>. The coil is arranged so that its plane is threaded by the magnet's field (the normal to the coil's plane is parallel to the field) in a non-uniform region of the field. Passage of current through the coil then produces forces which tend to move the coil in the plane in which it lies, imparting tensions or compressions to the sample.
>
> <u>Torsional Forces</u>. The coil is arranged so that its plane is parallel to the magnet's field in a reasonably uniform region of the field. Passage of current through the coil produces torque forces on the sample such as in an electric motor driving a shaft.

The forces are set up by currents flowing in the coils. These driving currents are a.c. so that the forces are vibratory in nature.

The wave velocities could have been obtained by direct measurements. However, instead of directly measuring the time of transit of a single disturbance, it was easier and more accurate to set up standing waves within the rod, much as

standing waves are set up on strings, and to compute the velocities from the exciting frequencies and corresponding wave lengths. Thus, if an alternating current were passed through the driver coil the forces produced would periodically change direction and a continuous series of disturbances would be produced. Each wave would propagate to the other end of the rod and be reflected. The reflected wave would return to the sending end and would be reflected from this end. This would continue for a single wave until it was damped out by internal friction forces. Since there would be many waves or portions of waves present in any section of the rod at a given time the total disturbance at this section would be the resultant of all the disturbances. As the frequency of the disturbance is varied certain frequencies would be reached so that the disturbance would have anti-node positions at the ends of the rod and the rod is then said to be in resonance. The velocity of propagation is found in terms of the resonant frequency of the disturbance, ν , and the length of the rod, L, by the expression

$$\text{velocity} = \lambda\nu = \left(\frac{2L}{n}\right)\nu_n ,$$

where λ is the wave length of the disturbance and n is the harmonic number of the disturbance.

The arrangement of the coils on the receiver or detector end of the rods and their placement in the magnets' fields correspond identically to that of their mates on the driver end of the rods. The motions of the coils in the magnetic fields generate signals that identify resonant conditions.

The required circuitry for the production and detection of the disturbances is shown in Figure 1. The transformers were used to match the low impedance of the coils to the high impedance of the rest of the circuit elements. The frequency meter, used to find the resonant frequency of the disturbance, was used in both the input and detection circuits as shown. The vacuum tube voltmeter required sufficient sensitivity to detect small signals from the detector coil.

CORRECTIONS

A number of corrections could be applied in an effort to improve the accuracy of the results. These include:

Correction for mass of coils attached to the rods. The coils which are attached to the ends of the rods can be considered as mass points which change the resonance frequency of the oscillations of the rods. To account for this change the resonant frequencies are corrected as follows: [3]

Longitudinal vibrations

$$\nu = \nu'\left(\frac{M+m}{M}\right)$$

where ν' is the observed frequency
M is the rod mass
m is the coil mass.

Torsional vibrations

$$\nu = \nu'\left(\frac{I_o + I}{I_o}\right)$$

where ν' is the observed frequency
I_o is the moment of inertia of the rod
I is the moment of inertia of the coil.

The corrections for the experimental arrangement used here are increases of

0.20 to 0.27% for longitudinal vibrations
0.07 to 0.11% for torsional vibrations.

The smaller corrections apply to the more dense explosives.

Correction for finite diameter of the rods. The rods are not strictly one-dimensional but have a finite diameter. This will result in dispersion of the acoustic waves since the radial extension of mass will act as confinement of the central region and will display inertia so that the rod does not respond immediately to applied stresses. The corrections necessary for the longitudinal sound velocities are of the form[4]

$$v \simeq v'\left[1 + \left(\pi n \sigma \frac{r}{2L}\right)^2\right],$$

where v' is the observed velocity
n is the harmonic number of the mode of interest
r is the rod radius
L is the rod length
σ is Poisson's ratio.

These corrections would amount to 0.05% or less for the experimental arrangement used here.

Detailed considerations of this type of correction have also been made by Bancroft[5] and Hudson[6] for both longitudinal and transverse waves. Their results, presented in graphical form for easy estimates of the general corrections that apply, would indicate that the corrections for the specific arrangements and waves of this experiment would be small -- much less than 1%.

Correction for viscous damping of the disturbance in the rod.[7] As the frequency of the disturbance is varied and the resonant frequency is attained, a significant change is observed in the signal indicated by the voltmeter. At resonance the end of the bar and consequently the attached coil are at a pressure node and a displacement anti-node so that the greatest displacement is observed. The sharpness of the peak signal going through resonance is related to the damping forces in the bar. A Q (quality factor) of the material can be defined for the nth resonant harmonic as

$$Q_n = (\nu'_{n+} - \nu'_{n-})/\nu'_n = \Delta\nu'_n/\nu'_n \ ,$$

where ν'_n is the observed frequency at peak signal
ν'_{n+} is the frequency above ν'_n where the signal drops to 0.707 of peak (half-power frequency
ν'_{n-} is the frequency below ν'_n where the signal drops to 0.707 of peak.

The resonant frequencies are then corrected for damping effects by a relationship of the form

$$\nu_n = \nu'_n \frac{2Q_n - 1}{2Q_n + 1} \ .$$

This correction amounts to a change in frequency on the order of 0.05% for the arrangements used here.

Correction for cavities and voids in the material. The most significant corrections that might be applied to the results are those that would account for the cavities and voids in the material, since the explosives considered in the experiment are not ideal perfect solids. They are materials of gross crystalline TNT structure having grains of solute explosive frozen into the TNT crystals

with cavities, air bubbles and low density regions that develop as the composition solidifies in the casting operation. The cavity and bubble defects may run up to 5% or more of the volume of the casting. Some of them are clearly visible in radiograms of the charges; others are invisibly, uniformly distributed throughout the charge. The effect of these defects on the elastic constants of the explosives can be estimated using the analysis of Dewey.[8] By her analysis Young's modulus and the modulus of rigidity of a nearly incompressible medium loaded with a gas at pressure p are given by

$$E' = E\left(1 + \frac{E}{9p+4E}\psi\right)$$

$$G' = G\left(1 - \frac{5}{3}\psi\right),$$

where ψ is the volume fraction of the gas and E and G are the ideal values of Young's modulus and the modulus of rigidity of the medium. For the present experiment these can be rewritten as

$$E = E'\left(1 + \frac{1}{4}\psi\right)$$

$$G = G'\left(1 + \frac{5}{3}\psi\right),$$

where E' and G' are the moduli computed on the basis of the experimental observations. For an explosive at 98% of theoretical maximum density E and G would be increased by 0.5 and 3.3%, respectively by this correction.

The experimental results will be presented both as observed and as corrected for significance in presenting valid values of sound velocities and elastic moduli.

THE CALCULATED SOUND VELOCITIES AND ELASTIC MODULI

The explosives considered in this work were all cast charges. TNT formed the casting matrix for all compositions. The additives were fine-particle solids suspended in the TNT. The crystalline structure of the charges was therefore basically TNT with a high concentration of impurities distributed throughout the grains and at the grain boundaries. The explosives considered were:

TNT
Comp B: (59.4/39.6/1) RDX/TNT/Wax
Comp B plus 1% wax
Comp B plus 2% wax
Comp B plus 3% wax
75/25 cyclotol: (75/25) RDX/TNT
50/50 pentolite: (50/50) PETN/TNT
H-6: (44.8/29.5/21/4.7) RDX/TNT/Aluminum/Wax
HBX-1: (40/38/17/5) RDX/TNT/Aluminum/Wax
67/33 baratol: (67/33) Barium nitrate/TNT.

Table I gives an indication of the typical resonant frequency measurements made in these experiments (in this case the compilation of the observations on TNT samples) and the computed sound velocities. It is observed that in any one set of measurements the computed velocities for different modes of excitation show a range of variability less than 1%. The reproducibility of velocities from one sample to the next, or from one experimental setup to the next, may be no better than 2 to 3%.

The determinations of resonant frequencies in TNT were carried out over a range of temperatures. There is an indication that the sound velocities drop as the temperature increases in the range considered (20 to 32°C). In the small range covered the variation could be within experimental error so that no attempt is made to describe the variation with temperature. It is noted that, in one observation, the transverse wave velocity at 60°C is some 10 to 12% lower than at 20 to 25°C. This is to be expected since the melting point of the material is being approached and the material is losing stiffness.

Table II gives the computed sound velocities, Young's moduli and the shear moduli for the different explosives considered in these experiments. These values are for the conditions of the explosive charges indicated without corrections. Table II also gives corrected values of the moduli for the correction factors indicated above. The principal correction is to adjust to conditions of theoretical maximum density (TMD) for the charges.

These velocities and moduli are given to three significant figures. While retention of the third significant figure may not be completely justified it is believed that the results are more accurate than would be indicated by retention of only two significant figures. The explosives chosen were common types that have fairly wide use. (The Comp B compositions with wax were included for possible comparison with previous work, e.g. Cramer[2]).

Table II shows values for two conditions of charge preparation of TNT. In one case the charge was 98.4% of TMD; in the other case the charge was 93.7% of TMD. There is a significant difference in the measured longitudinal sound velocities and a 30% difference in the computed Young's moduli. Charge preparation therefore has a very decided influence on the physical properties of these explosive charges. This is a factor that must be emphasized whenever physical properties are discussed. For the purposes here, the charge of higher density is taken as more representative of the material considered.

On a number of samples opportunity presented itself for making repetative measurements of sound velocities separated from the original measurements by one year. The charges had been prepared just prior to the original measurements. They were stored in an unheated magazine during the period between the original and subsequent measurements. Table III compares the sound velocity observations on these samples. The results (given here to four significant figures to point out the observed differences) indicate the possibility of a slight drop in sound velocities with the year's aging of the charges. This in turn could be interpreted as a slight decrease in the elastic moduli of the charges brought about by an age annealing of the charges. This is only speculated since no analyses of the crystalline structures of the charges were made. The effect appears to be well within experimental errors of measuring sound velocities in the charges so that no special significance is attached to the aging effect.

COMPARISON WITH OTHER MEASUREMENTS

Meleski has made determinations of the various elastic moduli for a number of explosives by use of mechanical testing procedures.[9] His results afford a direct comparison with the present work in the case of Young's moduli for several explosives.

Table IV presents a summary of the determinations of Young's moduli by stress-strain measurements which can be used in the comparison. Two types of charge preparation are indicated in Table IV:

Hot Cast. Hot cast explosives are heated to temperatures 15 to 20°C above the melting point of TNT. The melt is poured at this temperature into heated molds and allowed to cool slowly. This technique produces a course, large-grained crystalline structure.

Cream Cast. Cream cast explosives are heated above the melting point of TNT and then allowed to cool to just above the melting point of° TNT before pouring into the mold. The charge solidifies rapidly producing a fine, small-grained crystalline structure.

The data of Table IV are taken without interpretation. They indicate that the method of charge preparation has a significant effect on the value of Young's modulus for an explosive composition using TNT as the casting matrix in what appears to be a random manner. At the present time the nature of this influence, and how to control it, is not known.

Comparisons of Young's moduli measured by the two techniques are given in Table V. The comparisons are not good, but considering the spread in measurements of Young's modulus indicated in Table IV one should not expect much better agreement. The Young's moduli determined from velocity of sound measurements show considerably better agreement among themselves than the Young's moduli determined from stress-strain measurements.

The work of Cramer[2] can be used for further check of the present results in the case of TNT. Cramer was primarily interested in obtaining compressibility data for a number of explosives. No attempt will be made to use his compressibility data although the bulk modulus is related to Young's modulus and the shear modulus through the expression

$$K = \frac{EG}{9G - 3E}$$

where K is the bulk modulus, E is Young's modulus, and G is the shear modulus. Small uncertainties in E or G can lead to large errors in computing K. He did check his results for TNT using the sound resonance technique. His results and a comparison with present results are summarized in Table VI. The present results indicate sound velocities some 6 to 8% higher than those obtained by Cramer and moduli some 15 to 20% greater than those of Cramer. This disagreement is larger than desirable - well outside of experimental technique errors. The most probable reason for this discrepancy lies in the explosive charges. The charge used by Cramer had a density of 94.8% TMD while present charges used for the comparison had a density of 98.4% TMD. It was noted earlier

that charge preparation has a significant bearing on the sound velocity and elastic moduli determinations for TNT. If the observed variation of sound velocity and elastic moduli with density for TNT given in Table II is reasonable, the difference in densities of the charges explains the differences in velocities and moduli reported by Cramer and the present work. Jones[10] by similar techniques also obtained sound velocities and elastic moduli for TNT. The density of his charge was about midway between the density of Cramer's charge and the present charges. His results agree with those of Cramer to within 2 to 5% but are lower than to be expected if the discrepancy is to be attributed to differences in charge densities as indicated above.

SUMMARY

Sound velocity measurements and elastic moduli have been obtained for a number of different explosives. The measurements of velocities appear to be reproducible to 1 to 2%; the moduli derived from these velocities should therefore be reproducible to 2 to 4%. Young's moduli for several of the explosives obtained here can be compared to Young's moduli obtained by stress-strain measurements. The agreement is not good, but this is attributed to deficiencies in determining Young's modulus using mechanical testing techniques. Cast explosives with TNT as the casting matrix are not highly amenable for consideration as mechanical elastic materials. A comparison of the present results with those of other observers for TNT indicates that the present results give velocities some 6 to 8% higher than previously observed and elastic moduli some 15 to 20% higher. This disagreement is attributed to differences in charge preparation and differences in charge densities. There appears to be no appropriate way to account for charge preparation differences (although these certainly are important in determining the physical properties of the charges) except in the density of charges obtained. An attempt has been made to correct for density differences or deficiencies in the charges. There is no way to know if this has been satisfactorily accomplished, although fragmentary experimental evidence seems to show that the correction factor is not nearly large enough.

When the experiments were first considered it had been hoped that a correlation between the composition of the explosive charge and its elastic moduli would have been obtained. No such correlation was evident in the results of these experiments although this does not say that such correlation does not exist.

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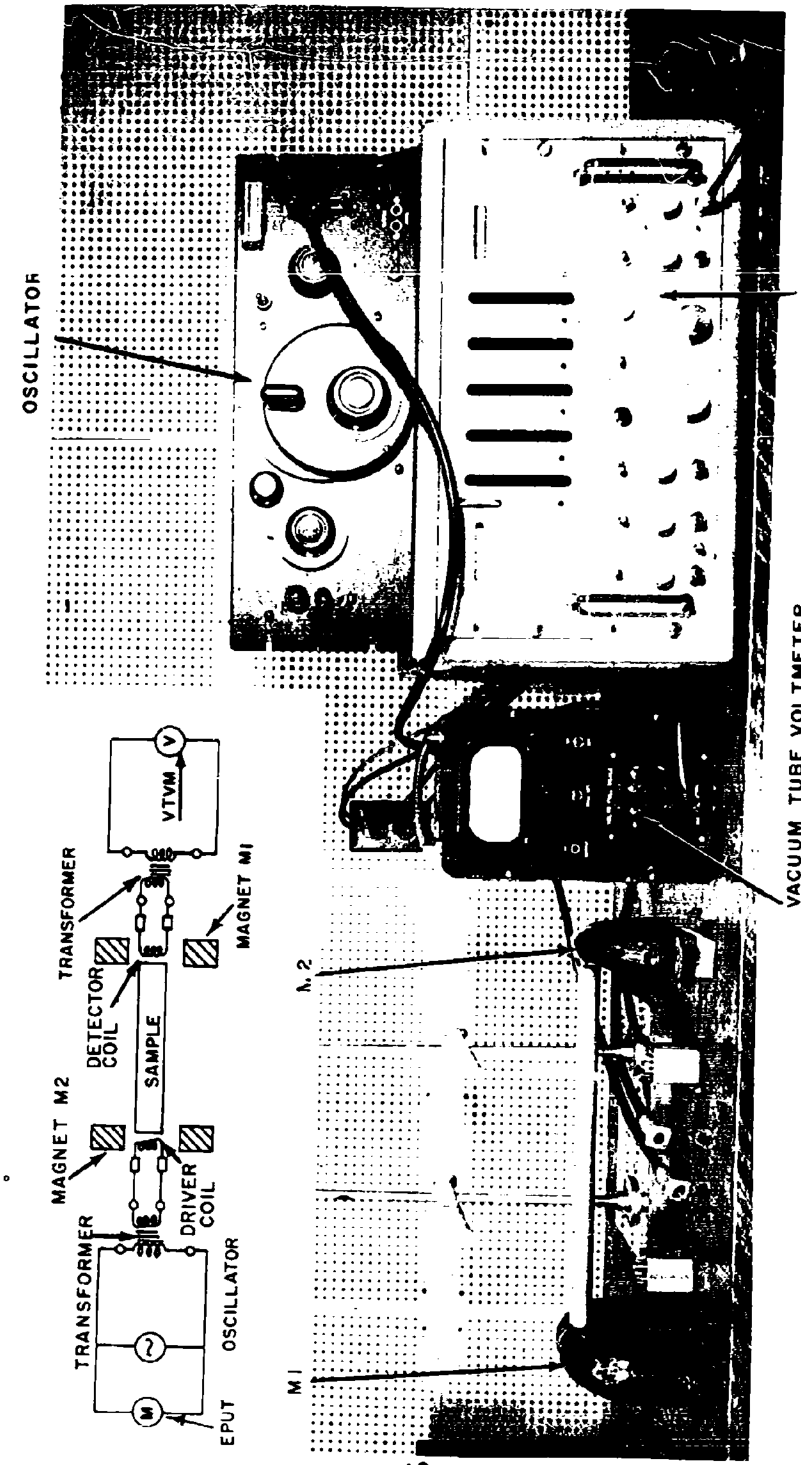

FIG. I EXPERIMENTAL SET UP

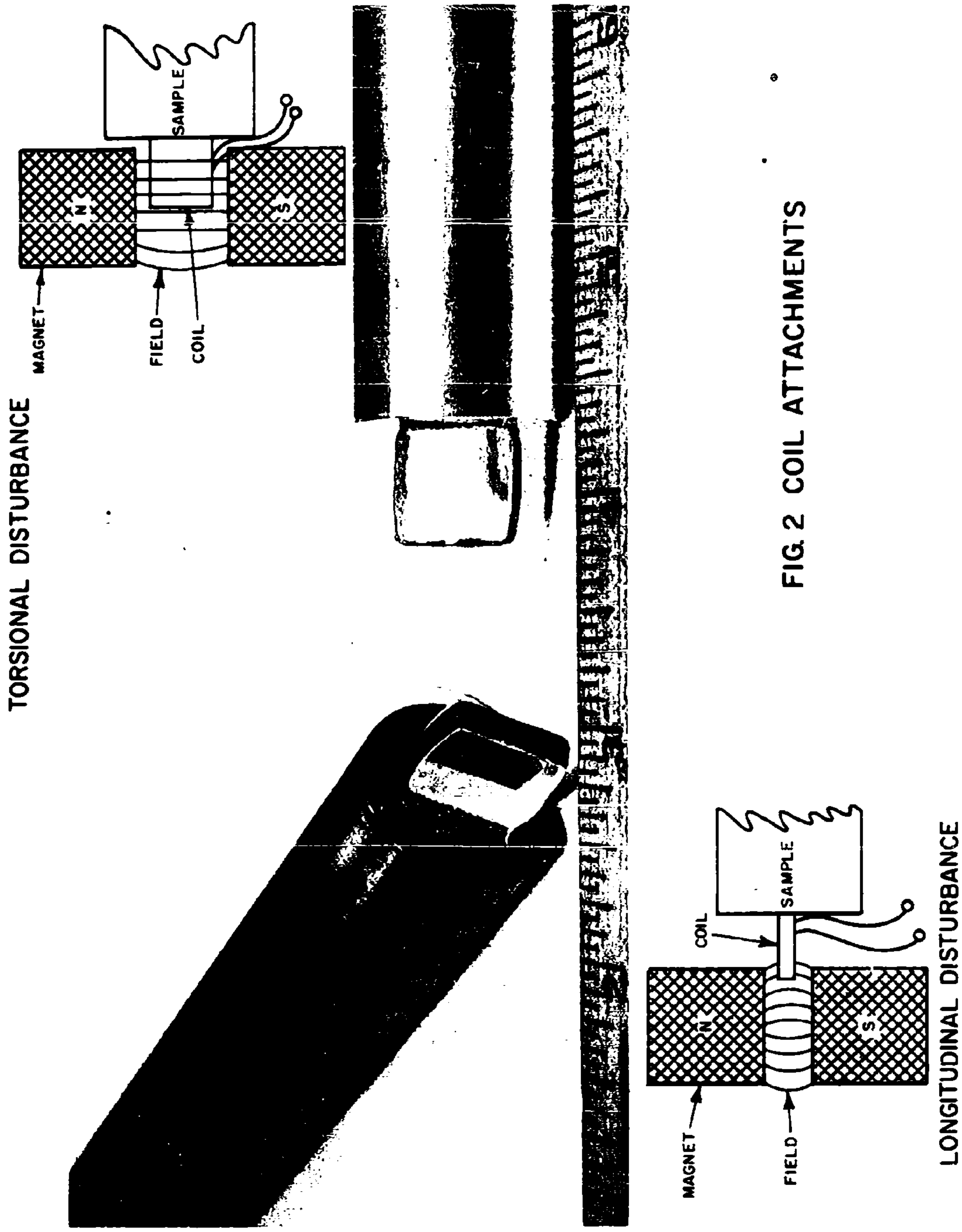

FIG. 2 COIL ATTACHMENTS

Table I. Typical Resonant Frequency Measurements and Computed Sound Velocities for TNT.

Bar Length (cm)	ρ (g/cm^3)	Percent TMD	Temp. (°C)	Resonant Frequencies (cycles/sec)		Sound Velocities (m/sec)	
				Long.	Tors.	Long.	Trans.
38.02	1.624	98.3	20	2 568	1 593	1 953	1 211
				5 172	3 188	1 966	1 212
				-	:		
				10 318	:	1 961	
					15 978		1 215
					-		
					19 185		1 216
					Average	1 960	1 213
38.07	1.628	98.4	21	2 686	1 678	2 032	1 277
				5 382	3 351	2 052	1 276
				-	5 032	2 056	1 277
				10 816	6 700		1 275
					:		
					13 430		1 278
					Average	2 047	1 277
37.98	1.624	98.3	28	2 523	1 584	1 916	1 203
				5 133	3 168	1 945	1 203
				7 699		1 947	
				10 294	6 316	1 952	1 199
				12 851	7 954	1 954	1 208
					:		
					12 711		1 207
					-		
					15 838		1 203
					-		
					19 037		1 205
					Average	1 943	1 204
38.08	1.628	98.4	32	2 606	1 640	1 985	1 249
				5 253	3 271	2 000	1 246
				7 678	4 873	1 949	1 237
				11 901	6 538	-	1 245
				13 187	8 175	2 008	1 245
					9 898		1 257
					:		
					16 357		1 246
					-		
					19 217		1 219
					Average	1 986	1 243
38.07	1.628	98.4	60		1 417		1 079
					2 851		1 086
					Average		1 082

Table II: Computed Sound Velocities, Young's Modulus, and Shear Modulus for Various Explosives. (Temperature range for measurements 22 to 25°C).

Explosive	ρ (g/cm^3)	Percent TMD	Sound Velocities (m/sec) Long.	Sound Velocities (m/sec) Trans.	Young's Modulus (dynes/cm^2)	Shear Modulus (dynes/cm^2)	Sound Velocities (corrected) (m/sec) Long.	Sound Velocities (corrected) (m/sec) Trans.	Young's Modulus (corrected) (dynes/cm^2)	Shear Modulus (corrected) (dynes/cm^2)
TNT	1.628	98.4	1 980	1 230	6.42×10^{10}	2.48×10^{10}	1 990	1 250	6.47×10^{10}	2.56×10^{10}
TNT(cream cast)**	1.550	93.7	1 720	-	4.57	-	1 730	-	4.65	-
Comp B	1.700	98.8	2 420	1 520	9.93	3.92	2 430	1 540	10.0	4.01
Comp B + 1% wax	1.685	97.7	2 290	1 570	9.05	4.16	2 300	1 600	9.14	4.33
Comp B + 2% wax	1.674	97.8	2 430	1 540	9.97	3.96	2 440	1 570	10.0	4.12
Comp B + 3% wax	1.659	97.8	2 410	1 520	9.68	3.86	2 420	1 550	9.77	4.02
75/25 cyclotol	1.712	97.4	2 510	1 560	10.8	4.17	2 520	1 600	10.9	4.36
50/50 pentolite	1.675	98.0	2 240	1 410	8.66	3.34	2 250	1 430	8.74	3.46
H-6	1.730	96.8	2 490	1 570	11.1	4.25	2 500	1 610	11.2	4.49
HBX-1	1.718	98.0	2 450	1 520	10.5	3.97	2 460	1 550	10.6	4.12
67/33 baratol	2.514	98.5	2 280	1 440	13.0	5.17	2 290	1 460	13.1	5.32

* TMD is theoretical maximum density.

** Cream cast refers to a method of charge preparation wherein the molten explosive is allowed to cool to a temperature just above the melting point before pouring into the mold. The charge solidifies very rapidly in this process.

Table III: Comparison of Sound Velocities of Several Explosives Taken on the Same Samples One Year Apart. (Temperatures 20 to 23°C.)

Explosive	ρ (g/cm^3)	Sound Velocities (m/sec) 1st Determination Long.	Trans.	2nd Determination Long.	Trans.
Comp B	1.70	2 319	1 470	2 428	1 514
50/50 Pentolite	1.67	2 233	1 410	2 207	1 395
50/50 Pentolite	1.67	2 252	1 411	2 220	1 405
H-6	1.72	2 490	1 566	2 430	1 533
HBX-1	1.71	2 454	1 524	-	1 505
HBX-1	1.71	2 441	1 516	2 411	1 497
67/33 Baratol	2.34	2 040	1 273	-	1 319

Table IV: Determination of Young's Modulus of Several Explosives by Direct Stress-Strain Measurements.* (At Temperature 24.7°C.)

Explosive	ρ (g/cm^3)	Preparation	Young's Modulus (dynes/cm^2)	Young's Modulus (corrected) (dynes/cm^2)
TNT	1.61	Cream cast	5.85×10^{10}	5.89×10^{10}
	1.61	Hot cast	5.85	5.89
Comp B	1.68	Cream cast	8.20	8.25
75/25 Cyclotol	1.71	Cream cast	14.6	14.7
	1.71	Hot cast	23.0	23.2
HBX-1	1.72	Cream cast	20.9	21.0
	1.72	Hot cast	13.8	13.9
67/33 Baratol		Cream cast	9.25	(9.33)**
		Hot cast	9.18	(9.25)**

* From NAVORD Report 4357.

** Correction based on an explosive density of 98% TMD.

Table V: Comparison of Young's Modulus for Explosives Derived from Sound Velocity Measurements with that Obtained from Stress-Strain Measurements.

Explosive	Young's Modulus* (Vel. of Sound Meas.) (dynes/cm^2)	Young's Modulus* (Stress-Strain Meas.) (dynes/cm^2)
TNT Cream cast	4.65×10^{10}	5.89×10^{10}
TNT Hot cast	6.47	5.89
Comp B	10.0	8.25
75/25 Cyclotol	10.9	23.2**
HBX-1	10.6	13.9
67/33 Baratol	13.1	9.25

* All values corrected to TMD.

** The value for cream cast charge preparation, $E = 14.7 \times 10^{10}$ dynes/cm^2, would give better agreement with E determined from sound velocity measurements.

TABLE VI: Comparison of Measurements of Elastic Moduli on TNT

Observer	ρ g/cm^3	Percent TMD	Sound Velocities (m/sec) Long.	Trans.	Young's Modulus (dynes/cm^2)	Shear Modulus (dynes/cm^2)	Bulk Modulus (dynes/cm^2)
Present Experiments	1.63	98.4	1 980	1 230	6.42×10^{10} (6.47)	2.48×10^{10} (2.56)	3.94×10^{10} (3.56)
Cramer	1.57	94.8	1 825	1 145	5.22 (5.30)	2.05 (2.22)	3.93 (2.88)
Jones	1.61		1 820	1 100	5.33	1.95	

Note: **Items in parentheses have been corrected to TMD charges.**

The agreement of Bulk Modulus values derived from the experimental measurements is purely fortuitous.

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